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*Nuclear Physics* **A110** (1968) 233—237; © *North-Holland Publishing Co., Amsterdam*



# PARTIAL PROTON WIDTHS OF ISOBARIC ANALOGUE STATES IN $^{38}$Ar

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Received 19 December 1967

**Abstract:** Isobaric analogue states of the three lowest levels in $^{38}$Cl were studied with the reaction $^{37}$Cl(p, p)$^{37}$Cl. Proton widths were determined of the resonances at $E_p$ = 1 138, 1 142 and 1 732 keV.

E | NUCLEAR REACTION: $^{37}$Cl(p, p), $E$ = 1.0-1.8 MeV; measured $\sigma(E_p; \theta)$. $^{38}$Ar deduced isobaric analogue resonances, $\Gamma_p$. Enriched target.

## 1. Introduction

The lowest four states in $^{38}$Cl, at $E_x$ = 0, 671, 761 and 1 311 keV, are $(d_{\frac{3}{2}})^{-3}$ $f_{\frac{7}{2}}$ states with $J^\pi = 2^-, 5^-, 3^-$ and $4^-$, respectively [1]). Their isobaric analogue states appear as resonances in $^{37}$Cl+p for proton energies between 0 and 2 MeV. Properties of these analogue states in $^{38}$Ar have been studied in this laboratory with different resonance reactions. The isospin-forbidden excitation of the analogue states with $J^\pi = 3^-$ and $J^\pi = 5^-$ was investigated by Bošnjaković *et al.* [2]) with the (p, $\alpha_0$) reaction; Erné *et al.* [3]) and Engelbertink *et al.* [4]) studied the preferential $\gamma$-decay from $T = 2$ analogue states to lower $T = 1$ states with similar shell-model configurations. One of the most important properties of an analogue state is the proton width, which is a measure of the single-particle character of the configuration. One might hope to obtain the proton width from an investigation of elastic proton scattering on $^{37}$Cl.

Because of the high $Q$-value for $\alpha_0$-emission ($Q$ = 3.03 MeV), one can expect that $\Gamma_p \ll \Gamma_\alpha \approx \Gamma$. This condition makes detection of a (p, p) resonance, the strength of which is proportional to $\Gamma_p^2/\Gamma$, extremely difficult if $\alpha_0$ emission is allowed. Fortunately, from previous (p, $\alpha_0$) and (p, $\gamma$) work it is known that, for the resonances to be considered, no significant channel spin or orbital momentum mixing is present; this facilitates the analysis.

## 2. Experimental technique

The experimental set-up has been described extensively elsewhere [2]). Here only details specific to this experiment will be given. The proton current of 300 nA is obtained from the Utrecht 3 MV Van de Graaff generator.

The target material, $BaCl_2$ enriched in $^{37}Cl$ to 99 %, is evaporated onto 10 $\mu g/cm^2$ carbon foils. The optimal target thickness is about 5 $\mu g/cm^2$. The stochiometric composition of the $BaCl_2$ target as measured from the relative intensities of the Ba and Cl elastic scattering peaks was found to remain unchanged during the experiment.

Charged reaction products are detected with silicon surface-barrier counters at lab angles of 172.0°, 154.3°, 148.6°, 139.7° and 123.9° relative to the beam direction. The solid angles are defined by circular aluminium diaphragms of 7.0 mm diam at a distance of 7.8 cm from the target. Detector pulses are amplified with a charge sensitive tube pre-amplifier and a RC-shaping main amplifier. Each main amplifier leads to one or two single-channel discriminators which are set with the aid of a multi-channel analyser and a pulse generator.

Alpha particles are detected in the same semi-conductor detectors and counted with separate single-channel discriminators. Gamma rays are detected with a 10 cm × 10 cm NaI scintillation counter, positioned at 135° at a distance of 18 cm from the target.

## 3. Data analysis and results

The method of analysis is developed from that described by Walinga *et al.* [5]). In the present investigation, however, one is confronted with the fact that the values of $\Gamma_p$ and $\Gamma$, which can differ by an order of magnitude, must be treated as independent variables. For all (p, p) resonances to be considered, the values of spin and parity $J^\pi$, channel spin $s$ and proton orbital momentum $l_p$ are already known from previous (p, $\alpha$) and (p, $\gamma$) work [2-4]). The purpose of the analysis was the determination of $\Gamma_p$ and, if possible, of $\Gamma$.

The differential cross sections computed by folding the theoretical expressions of Blatt and Biedenharn [6]) into an instrumental resolution function have to be compared to the experimental yield curves. The fit, measured by a $\chi^2$ value, is optimized by variation of the parameters $E_0$, the resonance energy, $\Gamma$ and $\Gamma_p$. The analysis yields proton widths with a relatively small experimental error, whereas $\Gamma$ remains practically undetermined. A search for (p, p) interference structure was carried out at the resonances with $E_p$ = 1 089 and 1 094 keV ($J^\pi = 5^-$), 1 138 and 1 142 keV ($J^\pi = 3^-$) and 1 732 keV ($J^\pi = 4^-$).

$E_p$ = 1 089 and 1 094 keV. No significant resonant effect was found in the elastic proton scattering. For each of the two resonances an upper limit of the (p, p) resonance strength is estimated as $(2J+1)\Gamma_p < 50$ eV.

$E_p$ = 1 138 and 1 142 keV. Two weak but significant (p, p) interference structures are found at the energies of the corresponding two $J^\pi = 3^-$ (p, $\alpha_0$) resonances [2]). The result of a multiple-pass run is shown in fig. 1. The (p, p) yield at 125° is not shown because at that angle the chlorine elastic peak could not be resolved well enough from the barium peak. The solid lines represent the best fit obtained from the analysis if one assumes the values of $J^\pi = 3^-$, $s = 2$ and $l_p = 1$, known from ref. [2]).

The analysis of several measurements yielded the following weighted mean values for $\Gamma_p$:

$$E_p = 1\,138 \text{ keV}, \quad \Gamma_p = 25\pm8 \text{ eV}; \quad E_p = 1\,142 \text{ keV}, \quad \Gamma_p = 12\pm3 \text{ eV}.$$

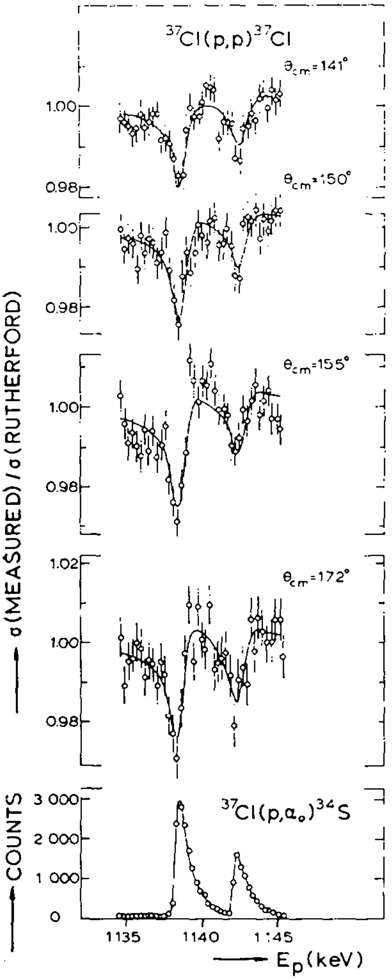


Fig. 1. Differential cross section for elastic proton scattering on $^{37}$Cl at four angles in units of the Rutherford cross section at the $E_p$ = 1 138 and 1 142 keV resonances. The drawn lines are best-fit theoretical curves for $J^\pi = 3^-$, $s = 2$, $l_p = 1$. The bottom curve gives the $^{37}$Cl(p, $\alpha_0$)$^{34}$S yield.

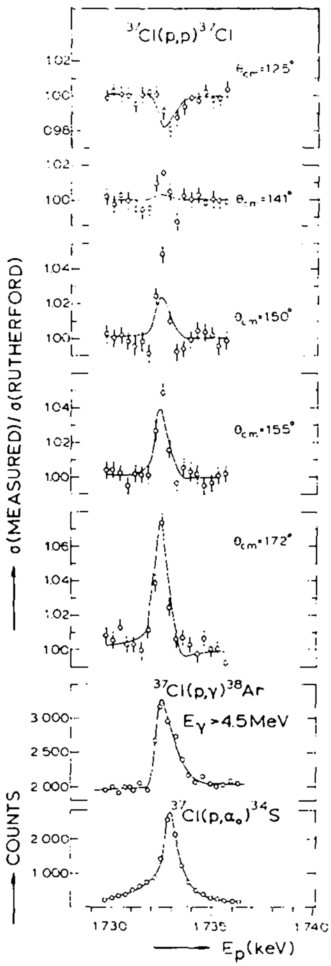


Fig. 2. Differential cross section for elastic proton scattering at the $E_p$ = 1 732 keV resonance. The drawn lines are best-fit theoretical curves for $J^\pi = 4^-$, $s = 2$, $l_p = 3$. The bottom curves represent the $^{37}$Cl(p, $\gamma$)$^{38}$Ar and the $^{37}$Cl(p, $\alpha_0$)$^{34}$S yields. For details, see sect. 3.

$E_p$ = 1 732 keV. At $E_p$ = 1 732 keV, a (p, $\alpha_0$) [ref. [2]] and a (p, $\gamma$) [ref. [4]] resonance were found. From (p, $\alpha_0$) work, $J^\pi = 1^-$ or $2^+$ was deduced, whereas the (p, $\gamma$) work led to a $J^\pi = 4^-$ assignment. To resolve the contradiction, a simultaneous measurement of the (p, p), (p, $\alpha_0$) and (p, $\gamma$) reactions was undertaken at this energy (fig. 2), which reveals the existence of a doublet. The energy of the (p, $\gamma$) resonance was found to be about 200 eV lower than that of the (p, $\alpha_0$) resonance.

The form of the (p, p) interference structure is in agreement with $J^\pi = 4^-$, $s = 2$, $l_p = 3$, but in disagreement with $J^\pi = 1^-$ or $2^+$. However, for $J^\pi = 4^-$, the analysis of the (p, p) resonance leads to a $\chi^2$ value just above the 0.1 % confidence limit. A more extended analysis, following the formalism of ref. [7]), was then carried out under the assumption that a $J^\pi = 4^-$ resonance interferes with a $J^\pi = 1^-$ or $2^+$ resonance. No significant improvement of the fit was achieved. This behaviour is not well understood; an explanation might be sought in a possible doublet character of the 1 732 keV (p, $\alpha_0$) resonance. This is supported by the rather unusual form of the (p, $\alpha_0$) resonance, which might indicate the superposition of a narrow resonance over a broader one.

Assuming that the (p, p) structure is essentially due to the $J^\pi = 4^-$ resonance, one finds a partial proton width of 22 eV. Because of the high $\chi^2$ value, the $\Gamma_p$ value may be wrong by a factor of two.

## 4. Conclusions

The measured values of $\Gamma_p$ for analogue states can be compared with the values predicted from the measured neutron spectroscopic factors in the $^{37}$Cl(d, p)$^{38}$Cl reaction [8]).

Theoretically, the reduced proton width $\theta_p^2$ of a $^{38}$Ar analogue state follows from the neutron spectroscopic factor $S_n$ of the corresponding $^{38}$Cl state by the relation $\theta_p^2 = S_n/2T$, with $T = 2$.

The analogue of the $J^\pi = 5^-$ level in $^{38}$Cl is split into two resonances at $E_p = 1\,089$ and 1 094 keV [ref. [3])]. In the present work, only upper estimates for $\Gamma_p$ are presented. One concludes that the sum of the proton widths $\Gamma_p(1\,098\text{ keV})+\Gamma_p(1\,094\text{ keV}) < 9$ eV. This result is compatible with the predicted value of $\Gamma_p^{\text{pred}} = 2.2$ eV.

The analogue of the $J^\pi = 3^-$ level of $^{38}$Cl is split into several components [2]). The two main contributors are the resonances at $E_p = 1\,138$ and 1 142 keV, which have $\Gamma_p\Gamma_{\alpha_0}/\Gamma = 23\pm8$ and $12\pm4$ eV, respectively [2]). The values of $\Gamma_p$ obtained in the present study, confirm the assumption of ref. [2]) that $\Gamma_p \ll \Gamma_{\alpha_0}$. For a detailed comparison of the proton widths with the neutron spectroscopic factor, see ref. [2]).

The $E_p = 1\,732$ keV resonance with $J^\pi = 4^-$ was identified as the analogue of the third excited state in $^{38}$Cl [ref. [4])]. The measured proton width amounts to 27 % of the predicted proton width $\Gamma_p^{\text{pred}} = 82$ eV. This rather low measured value is probably due to the difficulties in the analysis of the 1 732 keV (p, p) resonance (see sect. 3), but it is also possible that some part of the analogue state strength is distributed over several other (at present unknown) $J^\pi = 4^-$ resonances. The difference between the measured and predicted value of $\Gamma_p$ cannot be due to competition from the (p, $\alpha_1$)

and/or (p, n) reaction, because the low penetrability through Coulomb and orbital momentum barriers would make the corresponding partial widths unobservably small.

The authors are very much indebted to Professor P. M. Endt for suggesting this investigation, for his continuous advice and for his thorough criticism of the manuscript. The experience of Dr. J. Walinga was invaluable in the first stage of the experiment. The assistance of B.W.F. van Deursen and Th. W. J. Pieters in measurements and calculations is gratefully acknowledged.

This investigation was partly supported by the joint program of the "Stichting voor Fundamenteel Onderzoek der Materie" and the "Nederlandse Organisatie voor Zuiver Wetenschappelijk Onderzoek".

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